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FIXED-TARGET PHYSICS AT FERMILAB*

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I. INTRODUCTION TO THE PROGRAM

The Fermilab Energy Saver is now successfully commissioned and fixed-target experimentation at high energy (800 GeV) has begun. In addition, a number of new experiments designed to exploit the unique features of the Tevatron are yet to come on-line. In this talk, we will review recent accomplishments in the fixed-target program and describe experiments in progress and others yet to come.

It is important to realize that the energy improvement of the Tevatron means much more than just a factor of two in laboratory energy or 40% increase in center-of-mass energy. This occurs for several reasons:

1. First of all, in going from 400 GeV to 800 GeV laboratory energy one is crossing the threshold for production of systems containing bottom quarks. At the higher energy, the cross sections are anticipated to be between a factor of 5-10 greater than at the previous energies.
2. There is a major improvement in flux in the secondary hadron beams. This comes about because the higher energy superconducting transport lines accept a much larger bite in transverse momentum than was the case at lower energy.
3. There is a large improvement in duty factor, which used to be one second out of every ten or fifteen seconds. In present running it is about twenty seconds per minute.
4. The extra two-thirds of a unit of rapidity which is available in produced phase-space at the higher energies allows better separation of the various fragmentation regions for ordinary processes. In particular, there is emergence of the "central plateau" separating the target and projectile fragmentation regions. This is important for studies which attempt to sort out production mechanisms, and especially relevant for A-dependence studies. The difference between 200-400 GeV and 600-800 GeV is very significant.
5. The larger Lorentz factor for particles with short lifetimes, e.g. charm, can be useful in helping to sort them out from the collision debris.
6. While one might anticipate a lower flux for neutrino experiments because of the longer cycle time at the Tevatron, this is essentially compensated by the rise in the total cross section and the improvement in acceptance due to the smaller angular divergence of the neutrino beam.

Thus, for all of these reasons one may expect a qualitatively different situation at the Tevatron than has existed in previous machines, either the SPS or the Fermilab Main Ring.

The existing fixed target program is a very broad one, comprising about two dozen approved experiments. About a dozen of these will be on-line in the coming year. While these experiments cover a diverse set of topics, they can be roughly categorized into the following groups: heavy quarks, lepton- induced processes, hard collisions and tests of QCD. There are, in addition, studies of weak decays and magnetic moments, and strong interaction studies using polarized beams of p and $\bar{p}$. Table I exhibits the experimental program. The experiments in progress are classified into these categories. Figure 1 shows their location in the fixed-target area.

In the following sections of this talk, we will look at experiments by category, irrespective of their status in time; thus we look both at recent results and future programs.

Table I

Glossary of Approved Experiments in the Fermilab Fixed Target Program

ELECTROWEAK

E-632 WIDE BAND NEUTRINOS IN THE 15 FT. BUBBLE CHAMBER (Berkeley, Birmingham, Brussels, CEN/Saclay, CERN, Fermilab, Hawaii, IIT, Imperial College, MPI/Munich, Oxford, Rutgers, Rutherford-Appleton, Stevens, Tufts)

E-635 SEARCH FOR AXION-LIKE OBJECTS (Fermilab, VPI)

E-636 STUDY OF BEAM DUMP PRODUCED NEUTRINOS (Beijing, Brown, Fermilab, Haifa, Indiana, MIT, ORNL, Seton Hall, Tel-Aviv, Tennessee, Tohoku, Tohoku Gakuin)

E-646 STUDY OF PROMPT NEUTRINO PRODUCTION (Berkeley, Columbia, Fermilab, Hawaii, Rutgers)

E-649 NUCLEON STRUCTURE FUNCTIONS AT HIGH Q^2 (Fermilab, MIT, Michigan State)

E-652 NEUTRINO PHYSICS AT THE TEVATRON (Chicago, Columbia, Fermilab, Rochester)

E-665 MUON SCATTERING WITH HADRON DETECTION (Argonne, Cracow, CERN, Fermilab, Freiburg, Harvard, Maryland, MIT, MPI/Munich, San Diego, Washington, Wuppertal, Yale)

E-733 NEUTRINO INTERACTIONS WITH QUAD TRIPLET BEAM (Fermilab, Florida, MIT, Michigan State)

E-744 NEUTRINO PHYSICS WITH QUAD TRIPLET BEAM (Chicago, Columbia, Fermilab, Rochester)

E-745 NEUTRINO PHYSICS WITH QUAD TRIPLET BEAM (Beijing, Brown, Fermilab, Haifa, Indiana, MIT, Nagoya, ORNL, Tel-Aviv, Tennessee, Tohoku, Tohoku Gakuin)

DECAYS AND CP

E-621 MEASUREMENT OF η_{+-0} (Michigan, Minnesota, Rutgers, Wisconsin)

E-721 CP VIOLATION (Arizona, Athens, Duke, McGill, Northwestern, Shandong)

E-731 MEASUREMENT OF ε'/ε (CEN/Saclay, Chicago, Elmhurst, Fermilab, Princeton)

HEAVY QUARKS

E-653 HADRONIC PRODUCTION OF CHARM AND B (Aichi, Carnegie-Mellon, Chonnam, UC/Davis, Gifu, Gyeongsang, Jeonbug, Kobe, Korea, Nagoya, Ohio State, Okayama, Oklahoma, Osaka City, Osaka Sci. Ed. Inst., Sookmyong Womans, Toho, Won Kwang)

E-687 PHOTOPRODUCTION OF CHARM AND B (Colorado, Fermilab, Illinois, INFN/Frascati, INFN/Milano, U. Milano, Northwestern, Notre Dame)

E-690 STUDY OF CHARM AND B PRODUCTION (Columbia, Fermilab, Massachusetts, Mexico)

E-691 PHOTON PHYSICS WITH TAGGED PHOTON SPECTROMETER (UC/Santa Barbara, Carleton, CBPF/Brazil, Colorado, Fermilab, NRC/Canada, Oklahoma, Sao Paulo, Toronto)

E-705 CHARMONIUM AND DIRECT PHOTON PRODUCTION (Arizona, Athens, Duke, Fermilab, McGill, Northwestern, Shandong)

E-743 CHARM PRODUCTION IN PP COLLISIONS (Aachen, Brussels, CERN, Duke, Fermilab, Florida State, Coll. of France, Kansas, LPNHE/France, Michigan, Michigan State, Mons, Notre Dame, Strasbourg, Vanderbilt)

HARD COLLISIONS

E-605 LEPTONS AND HADRONS NEAR THE KINEMATIC LIMIT (CERN, Columbia, Fermilab, KEK, Kyoto, Saclay, SUNY/Stony Brook, Washington)

E-672 HIGH P_T JETS AND HIGH MASS DIMUONS (Arizona, Caltech, Chicago Circle, Fermilab, Florida State, George Mason, Indiana, Maryland, Rutgers, Serpukhov)

E-683 PHOTOPRODUCTION OF HIGH P_T JETS (Arizona, Fermilab, Lehigh, Rice, Vanderbilt, Wisconsin)

E-704 EXPERIMENTS WITH POLARIZED BEAM FACILITY (Argonne, Austin, UC/Berkeley, Fermilab, KEK, Kyoto, LAPP/France, LBL, Northwestern, Rice, Saclay, Serpukhov, Trieste)

Table I (cont)

E-706	DIRECT PHOTON PRODUCTION (Delhi, Fermilab, Michigan State, Minnesota, Northeastern, Pennsylvania, Pittsburgh, Rochester, Rajasthan)
E-711	CONSTITUENT SCATTERING (UC/Davis, Fermilab, Florida State, Michigan)
OTHERS	
E-466	NUCLEAR FRAGMENTS (Argonne, Chicago, Chicago Circle, Purdue)
E-508	EMULSION/MULTIPARTICLE PRODUCTION (Cracow, Louisiana State, Tashkent)
E-524	EMULSION/PROTONS GREATER THAN 500 GEV (Washington)
E-576	EMULSION/500 GEV PROTONS (Belgrade, Fermilab, Lund, Lyon, Nancy, Ottawa, Paris VI, Santander, Strasbourg, Valencia)
E-750	EMULSION/MULTIPARTICLE PRODUCTION (Delhi)
E-751	EMULSION/1 TEV PROTONS (SUNY, Buffalo)
E-753	CHANNELING STUDIES (Bell Northern Research, Chalk River, Fermilab, New Mexico, SUNY/Albany)
E-754	CHANNELING TESTS (Case Western Reserve, Fermilab, GE R&D Center, Sandia, SUNY/Albany)

II. WEAK DECAYS AND MAGNETIC MOMENTS

Perhaps the most important recent result from Fermilab is the measurement (E-617) of ε'/ε shown in Figure 2. The result is consistent with zero and begins to put constraints on the standard Kobayashi/Maskawa-plus-penguin picture of CP violation. The theoretical uncertainties are large and one cannot claim disagreement at this time. Perhaps the main result of this measurement is to decrease if not eliminate the theoretical hubris surrounding the attempts to calculate or minimize uncertainties in the long distance contributions to the $K\bar{K}$ mixing phenomenon. Also shown in Figure 2 is the recent Yale/Brookhaven measurement, which also shows consistency with zero. The E-617 group is now rebuilding their apparatus and will soon embark on new measurements (E-731) using the same technique. The anticipated improvements in the control of both systematic and statistical errors should considerably reduce the uncertainty in the result.

A highlight of the Fermilab program for many years has been the systematic measurement of the polarization of leading hyperons together with measurements of their magnetic moments. This program is nearly complete at this time, as shown

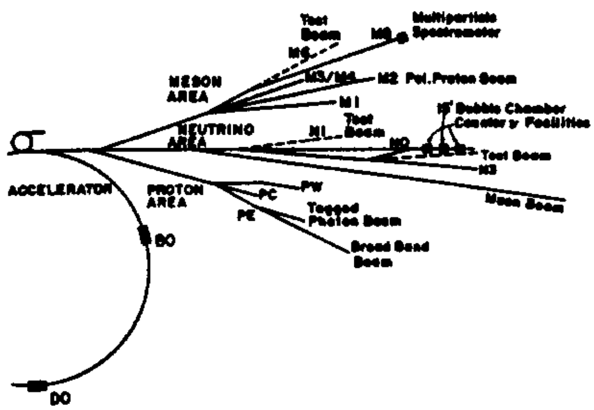

Fig. 1. Fermilab secondary beams and the locale of experiments.

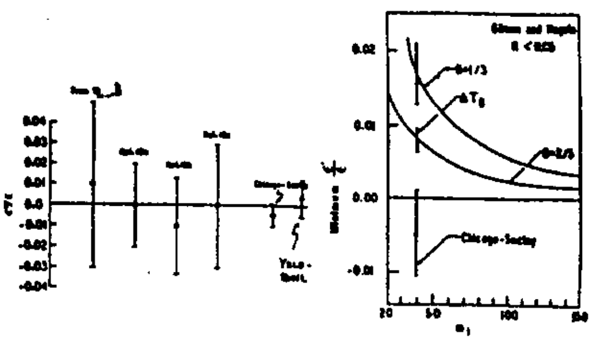

Fig. 2. Comparison of measurements of the CP violation parameter ε'/ε and theory.

in Table II. There is, let us say, 10-15% agreement with the quark model predictions. The accuracy of the measurements has reached a point where the comparisons are dominated by theoretical systematic errors rather than experimental ones. It remains to be seen how much these can be beaten down by theorists in the future.

There has been a nagging discrepancy with the standard model in old measurements of the electron asymmetry in the β-decay of polarized Σ^- hyperons. A new Fermilab experiment (E-715) has very beautifully remeasured this quantity, and the results have been reported to this meeting. They are shown in Figure 3. Whereas the old measurements disagreed with Cabibbo theory in magnitude and sign, the new measurement is decisively in accordance with the predictions. Had this not occurred, there would have been mass suicide in the theoretical community. It would have been very hard to accommodate the old results within the standard picture.

Another CP measurement is underway at Fermilab. A group from Michigan, Minnesota, Rutgers and Wisconsin (E-621) is attempting the ambitious, difficult task of measuring CP violation in the three-pion decays of the K_S and K_L; in other words to measure η^{+-o}. This experiment, which uses a double beam technique, has been set up and has taken some test data. Production running will commence in the next running period. The experimentalists hope to reach the 10^{-3} level where there is expected to be an effect. However, the problems of systematic errors are difficult and it remains to be seen how close they really will get.

III. ELECTROWEAK PARAMETERS

Neutrino physics by now has become a rather mature subject, with a demanding level of precision. Recent results (E-616) from the CCFRR group on structure functions are shown in Figure 4. They show that the QCD scale parameter Λ is beginning to be determined quantitatively, although there is still some way to go. That there is some way to go is best shown in Figure 5 which exhibits measurements of total cross section. The linear rise with energy is well

Table II

Baryon Magnetic Moments[a]

Baryon	Experimental μ, units $e\hbar/2m_pc$	Quark Model Prediction	$\mu-\mu_Q$	$g/2-1$
p	2.7928456(11)	input	-	1.79
n	-1.91304184(88)	input	-	-
Λ	-0.6138 ± .0047	input	-	-
Σ^+	2.357 ± 0.012	2.67	-0.30 ± .01	2.00 ± 0.014
$\lvert\Sigma^o\to\Lambda\rvert$	$1.82\ ^{+2.5}_{-.18}$	-1.63	$-.19\ ^{+.28}_{-.18}$	-
Σ^-	-1.151 ± 0.021	-1.09	-.06 ± .021	0.47 ± .03
Ξ^o	-1.253 ± 0.014	-1.43	+0.18 ± 0.014	-
Ξ^-	-0.69 ± 0.04	-0.49	-0.20 ± 0.04	-0.03 ± 0.05

a) Data from Rev Mod Phys <u>52</u>, S1 (1980), except for μ_{Σ^+}, μ_{Σ^-}, μ_{Ξ^o}, and μ_{Ξ^-}.

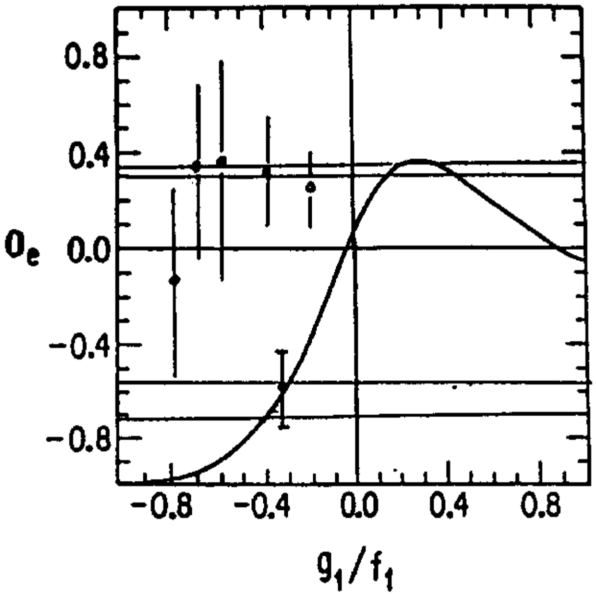

Fig. 3. Comparison of measurements of the electron asymmetry in Σ^- β-decay with theory.

verified, but there are also clear systematic differences between the set of measurements of CCFRR and their European competition CDHS. This simply shows that the business of precision measurements in neutrino reactions still has a way to go when pushing below the 10% level of

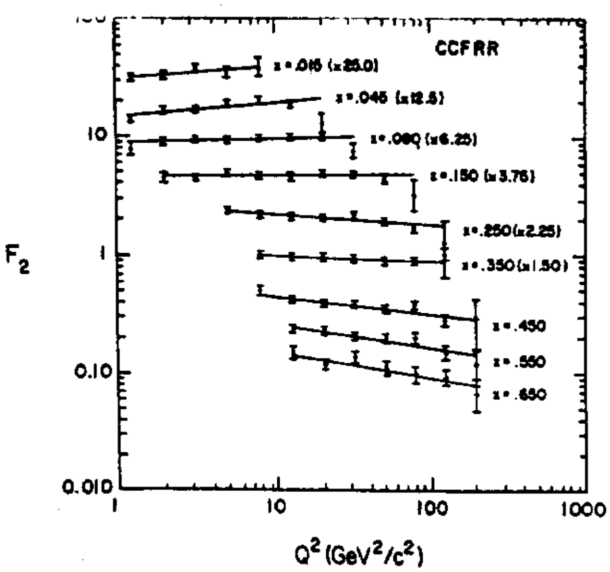

Fig. 4. Structure function F_2 as measured by the CCFRR group at Fermilab.

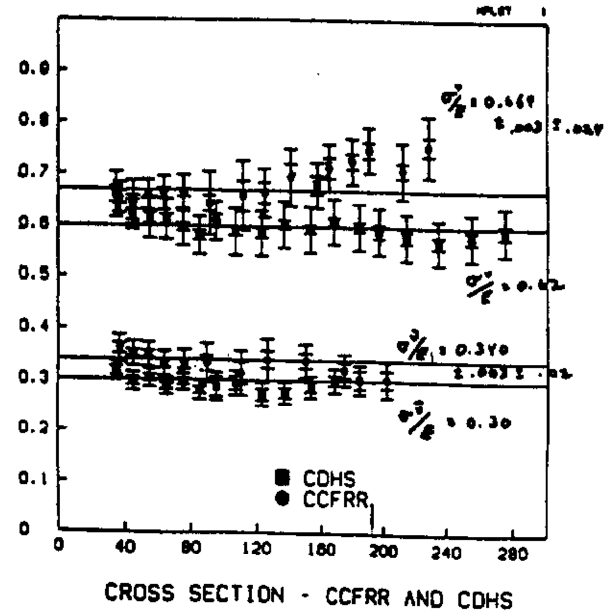

Fig. 5. Neutrino total cross-sections as measured by CCFRR and CDHS.

accuracy. The downstream neighbors (E-594) of the CCFRR experiment, one which emphasizes neutral current physics, has also reported new data to this meeting (Fig. 6). The ratio of x distributions from neutral currents to those for charged currents are seen to be independent of x as expected from standard electroweak theory. Some typical events from this fine grained calorimeter are shown in Figure 7. Both experiments also measure the ratio of neutral current to charged current cross sections. The numbers, as reported to this meeting are shown below, along with the new result from the neutrino-electron scattering experiment at Brookhaven reported at this meeting:

$\sin^2 \theta_W$ = .242 ± .010 ± .005 CCFRR

.243 ± .014 ± (⁻.014) FNMM (preliminary)

.209 ± .029 ± .013 BNL

IV. QCD AND HADRON STRUCTURE

Cross-section measurements in neutrino beams impinge as much on QCD properties as on electroweak theory. We have already mentioned Λ

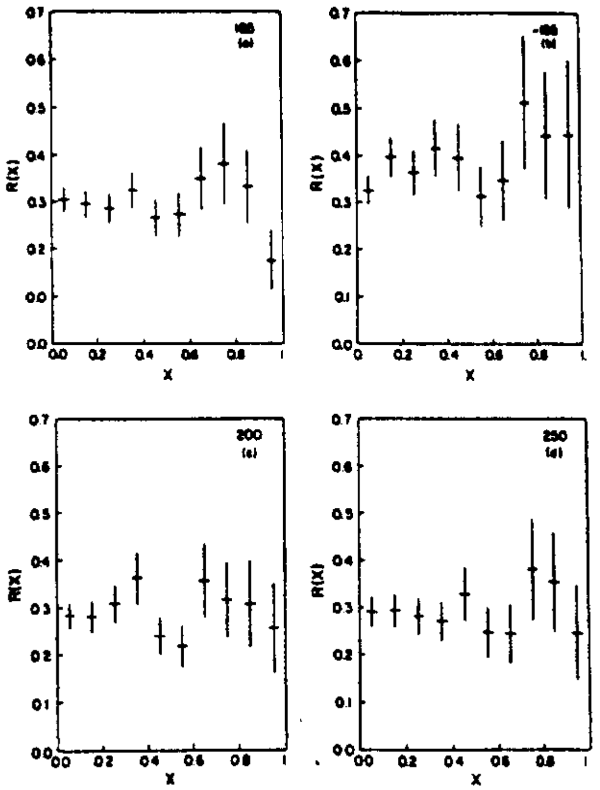

Fig. 6. Dependence on scaling variable X of the ratio of neutral-current and charged-current structure functions as measured by the FNMM group (E-594) at Fermilab.

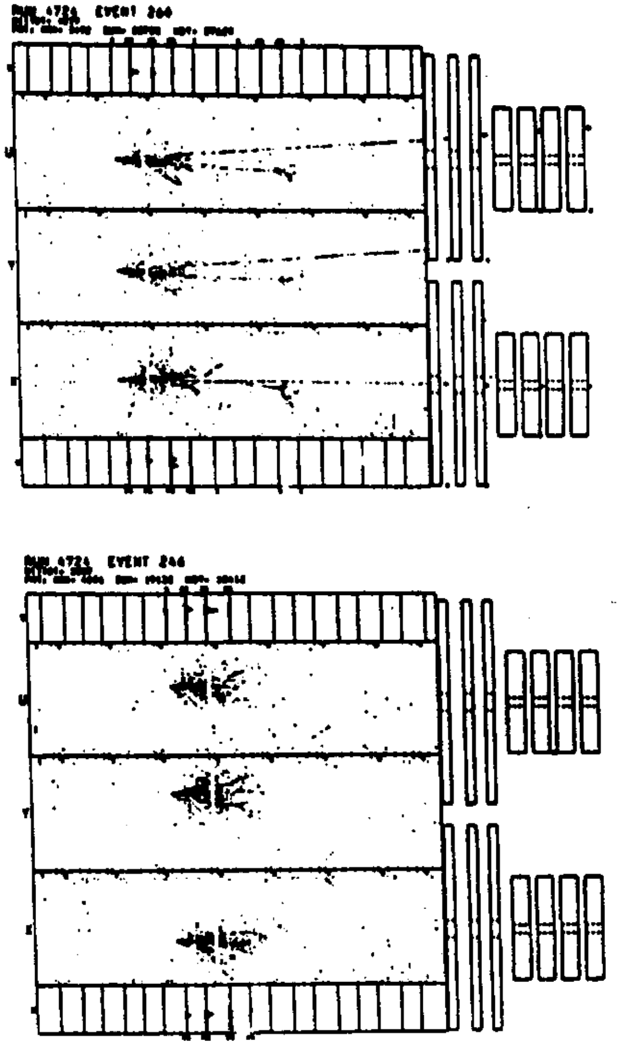

Fig. 7. Typical events as seen in the FNMM calorimeter.

determinations from charged current data. CCFRR has measured rather well the structure function xF_3 as shown in Figure 8. Especially interesting to me is the determination of the Regge asymptotics at small x and the establishment of the Gross-Llewellyn-Smith sum rule (including QCD radiative corrections). Structure functions from both neutrino scattering and muon scattering experiments at Fermilab and CERN are in reasonably good agreement with QCD and with each other. A new round of muon scattering experiments (E-665) in a vastly improved beam and at much higher energy is being prepared at Fermilab. A large spectrometer using the Chicago cyclotron magnet and vertex spectrometer from the CERN EMC experiment is now being installed. The experiment will be commissioned in the 1986 running period.

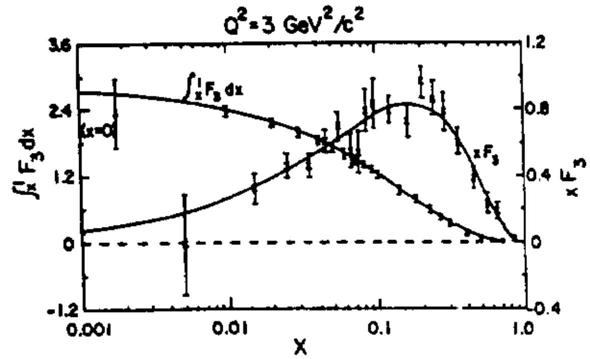

Fig. 8. The structure function XF_3 as measured by CCFRR.

Principal goals of that experiment are the study of the A-dependence of structure functions and of the hadronization process.

We now turn to QCD tests done with incident hadrons. There is quite a variety of them in the program, using many different techniques. Reported at this meeting are results from experiment E-615, which looks at forward Drell-Yan dileptons. As the Feynman x variable approaches unity, it was predicted by Berger and Brodsky that the dilepton angular distribution should change from the usual $1+\cos^2\theta$ behavior toward a $\sin^2\theta$ behavior as a consequence of "higher twist" non-scaling contributions. This is very clearly seen in the data (Fig. 9). Not anticipated by the theorists is a decreasing value of mean transverse momentum of the dilepton in the same limit.

Another result reported at this meeting comes from measurements (E-609) of dijet production from incident pions and protons. The history of jet production in fixed target experiments has been a checkered one. If one tries to trigger on jets with a total transverse energy trigger, such as done in the collider experiments at CERN, one is swamped by a background from azimuthally isotropic events of very high multiplicity. These events are interesting in their own right but do not seem to have much to do with simple binary QCD hard collisions. However, there is increasingly strong evidence that the jets are there, albeit buried in heavy background, and that other triggers which are sufficiently unbiased to be convincing may be used to pull out the jet signal. One successful example demands at least two isolated high p_T particles above a prescribed p_T threshhold irrespective of their azimuthal correlation. This trigger succeeds in producing events of high planarity. Indeed, as the total E_T of the events increase, the planarity increases despite a constant threshhold p_T. Thus by this and other means E-609 has with reasonably convincing arguments produced a differential cross section for inclusive jet production which in fact agrees reasonably well with QCD expectations.

Another interesting result from E-609 is the comparison of the jet production in pion beams relative to proton beams. Another idea of Berger

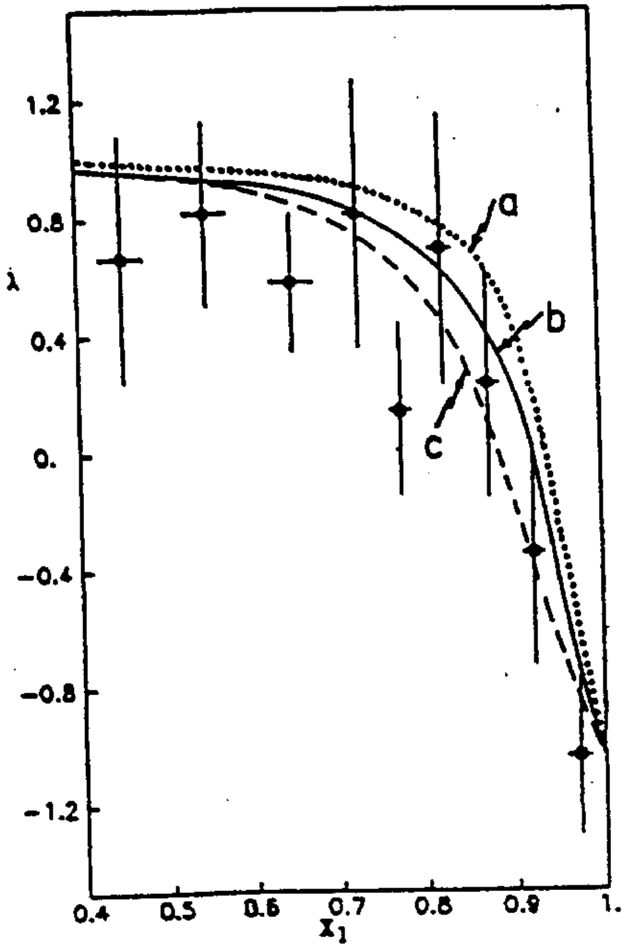

Fig. 9. Angular distribution of forward Drell-Yan dileptons as measured by experiment E-615.

and Brodsky is that some of the time the pion behaves like a point-like particle, when the quark and antiquark of the pion are atop each other and produce no source of gluon field. If this configuration does exist within the pion, then on arrival at the target it may diffractively dissociate into a pair of jets without production of any beam jet. For a proton primary this would be less likely because of the three quarks rather than two. Very preliminary data presented to this meeting by E-609 show (Fig. 10) an excess of events in which there is little or no forward "beam jet" energy. Whether this is simply a reflection of the stiffer quark distribution in the pion relative to the proton is not clear at this time and requires considerably more analysis.

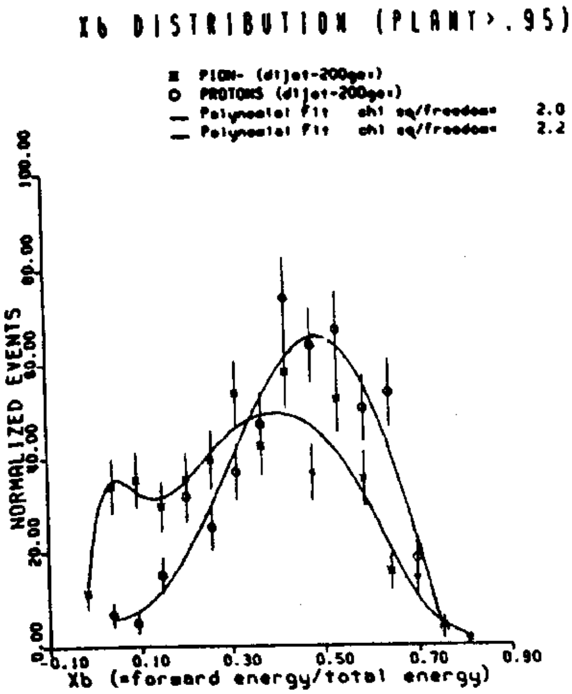

Fig. 10. Distribution of the fraction of incident energy contained in the E-609 beam-jet calorimeter.

However what is clearly shown is that jet phenomena produced by pion beams differs significantly from those in proton processes.

A variant of this same idea will be pursued by experiment E-683, which uses a photon in the initial state to produce two jets. Half the time the photon is not "vector-dominated" by ρ, but is, on arrival at the target, believed to be a bare $q\bar{q}$. If that is the case it can also materialize into a jet pair without any beam jet being produced in the direction of the initial photon. It is this process for which the experimentalists will search. This is a considerably cleaner situation than for pion-induced dijets.

To go further in the study of fixed-target hard collisions will probably require more precisely defined experimental quantities than the rather amorphous objects of 5-10 GeV p_T which are difficult to accurately define as jets, especially given the very steeply falling production spectrum. One attempt to do this is via measurement of leading dihadrons of high p_T. This is attempted in two experiments: E-605 is a very high resolution spectrometer which observes dihadrons produced symmetrically at 90° in the center-of-mass, with rather small angular acceptance. Complementary to this is experiment E-711, which will look at charged dihadrons without further particle identification but with very large angular acceptance. E-605 has taken data, which is now under analysis. E-711 is under preparation and should run during this running period.

Another attack is to look at direct photons produced in hard collisions. The direct photon process provides a precise measurement in terms of the yield of inclusive photons as a function of their kinematic angle and transverse momentum. The presence of this electromagnetic particle also makes theoretical calculations easier and less ambiguous. A new experiment (E-706) will not only measure photons with high precision and very large coverage but will also look at the properties of the associated jets.

Yet another approach is to study onia, in particular χ states presumably produced by glue-glue annihilation. Limited data (Fig. 11) already exists from Fermilab experiments E-610 and E-673 on this. To my knowledge, the results don't agree very well with simple theories, and in any case a much more extensive data sample will be required to make incisive comparisons. Experiment E-705, now being set up, will do this and should increase the sample of χ states decaying into $\psi\gamma$ by an order of magnitude.

The precursor of this experiment (E-537) produced very good data, presented to this meeting, on antiproton annihilation on heavy targets into dimuons. From this process one may quite directly determine the valence-quark structure of the projectiles. Figure 12 shows the resulting x distribution of quarks in the antiproton and QCD comparisons. The agreement is quite satisfactory.

An additional experiment which will probe the dynamics of hard collisions is experiment E-672 which will observe hadrons in association with ψ and Drell-Yan dilepton production. Also, experiment E-704 will examine a variety of soft

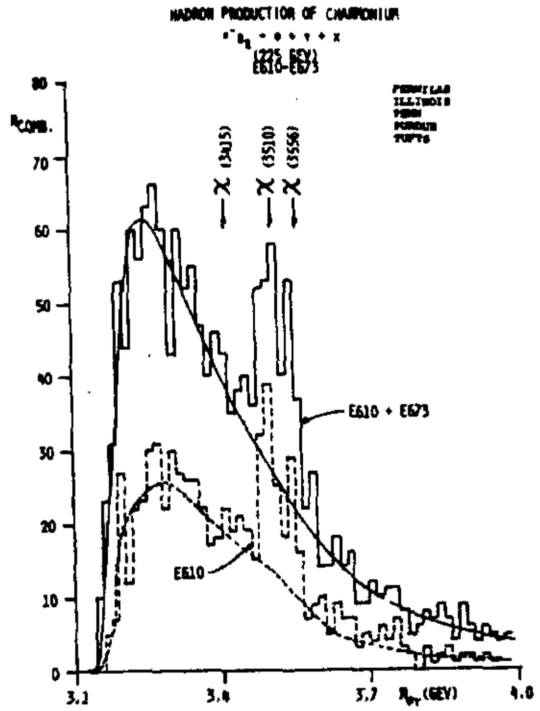

Fig. 11. Observation of hadronically produced χ states in experiments E-610 and E-673.

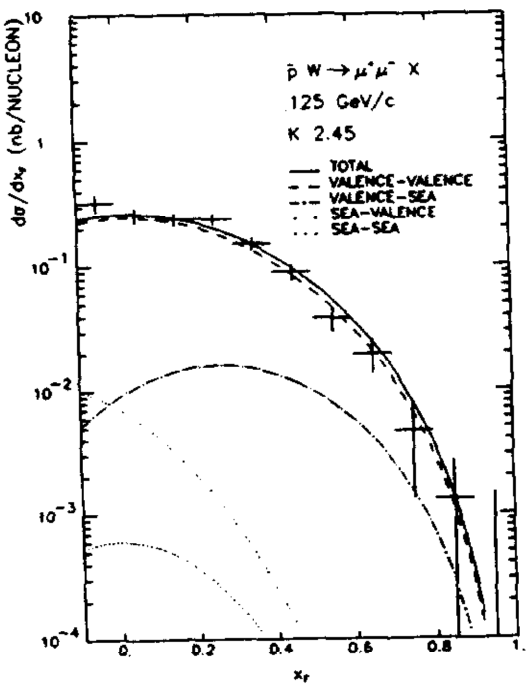

Fig. 12. Valence-quark structure function as determined from $\bar{p}$ induced Drell-Yan dileptons; experiment E-537.

and hard processes with incident polarized protons and antiprotons. Polarized beam and/or polarized target experiments are a very good constraint on theoretical model building. There is nothing which ensures the continued humility of theorists as well as measurements of polarization phenomena. Theorists who successfully explain unpolarized data are often brought to their knees when the polarization information comes in.

V. HEAVY QUARK PHYSICS

In principle prospects for charm and bottom physics at a fixed target hadron machine are great. Given 10^{11} interacting hadrons per experiment, one may expect a yield of 3 million produced $b\bar{b}$ and 100 million produced $c\bar{c}$ pairs. This easily exceeds the world production of such quantities in e^+e^- collisions from now into the foreseeable future - including Z factories such as LEP and SLC. Of course the problem is signal-to-noise. In addition to all those bottom and charm quarks there is a tremendous number of ordinary ones produced as well. Whether a fixed target program in heavy quark physics can compete with e^+e^- colliders is therefore a serious issue. I think it is too early to tell what the ultimate situation will be. But I do feel that there is real cause for optimism in the case of hadron machines, and that there is good reason to fight the good fight against the evil backgrounds to the bitter end. In terms of technique there is at least one advantage of hadron machines, in that one may see the vertices of the events better than one does in e^+e^- processes. This is sure to help on an event-by-event basis, where one may hope to unscramble which track came from which vertex in a better way than can be done in colliders.

The physics case for looking at heavy quarks produced in hadron beams goes beyond simply the possibility of being able to find more than one finds in e^+e^- collisions. There is the possibility of having a greater variety of hadrons containing heavy quarks to study. In particular, baryons may well become much more interesting as the properties of mesons are flushed out and well determined by the e^+e^- colliders. In terms of understanding strong interaction dynamics certainly baryon structure may be a more crucial test than the rather boring two-body potentials which one uses for the mesons. If there are strings, do they imply intrinsic three-body forces as well as pair forces within a baryon? Table III shows the variety of different kinds of mesons and baryons one may hope to see. Already there is some evidence for the usc and ssc baryons. Some of my other favorites are the ccd and possibly ccs. Further down the list one has to be optimistic in hoping that one can find them in hadron beams, but things such as the bcd or bss would be most interesting to find. The $b\bar{c}$ meson should also be interesting to observe. It is not clear whether e^+e^- or hadron machines are a better way to make it - it's not easy for anyone.

What is important about the physics of charm and bottom? In the case of hadron collisions, production dynamics should teach us more about QCD. It is simply not understood at present. Normalization and energy dependence of the cross section, A-dependence of the cross section, x-dependence of the cross section, and beam dependence of the cross section are only a few of the major uncertainties. Beyond QCD production dynamics, the spectroscopy and decay properties are of great interest. In particular the bottom quark is especially beautiful. Its long lifetime implies that it undergoes in some sense a forbidden decay. Therefore the b should be more sensitive to rare, hidden phenomena. That is, the branching ratio associated with a rare process will be larger for bottom than for other quarks simply because the total width is smaller. In the field of b-decays, the e^+e^- colliders at present are far ahead. But in the long run it may be important to study a variety of weak decays of bottom (and charm) particles for the same reason it was important for the strange system. The basic parameters such as Cabbibo angles were determined through a variety of experiments, not just a single one. Overdetermination of these parameters make their measured values more credible. In the case of heavier quarks one believes that simple spectator and/or "factorization" models should be more reliable. Nevertheless there have already been surprises in the charm system, and surprises in the bottom system are not yet ruled out. The more measurements that become available the better can be our confidence in determining the very important basic parameters of standard model.

What have hadron beams provided us in charm and bottom physics thus far? In bottom physics, it of course gave us the Υ itself. But beyond onia, there is not much at all. In charm physics, information on lifetimes have been found from a variety of experiments, most of which originated in hadron beams using high precision vertex detectors, such as nuclear emulsion or bubble chambers. In Figure 13 a recent summary of these determinations are given. In terms of the number of reconstructed charm particles per exclusive decay channel, hadron-induced processes were until recently competitive with e^+e^- induced processes. As an example, in a photoproduction experiment at Fermilab (E-~~617~~ 516), very clear D^* signals have been seen (Fig. 14). Another intriguing result has been presented to this meeting from experiment

Table III

Catalogue of $Q\bar{Q}$, Qqq, QQq, and QQQ States of Future Interest

Particle	Number Produced in Typical Experiment	Comments
$c\bar{u}$ $c\bar{s}$	$\sim 10^8$ 10^7	Bread and butter
$b\bar{u}$ $b\bar{s}$	$\sim 3\times10^5$ 3×10^4	Learn from CESR/ DORIS what to do
$b\bar{c}$	3×10^3?	Possible?
cud cuu cdd	$\sim 10^7$	Large samples should be found
usc ssc	$\sim 10^6$ 10^5	Found already
bud buu bdd	$\sim 3\times10^4$	Find them!
ccd ccs	$\sim 10^4$ $\sim 10^3$	Possible?
bus bss cub	$\sim 3\times10^3$? 300? 300?	Marginal
bcs ccc bcc bbc . . .		Prayers required

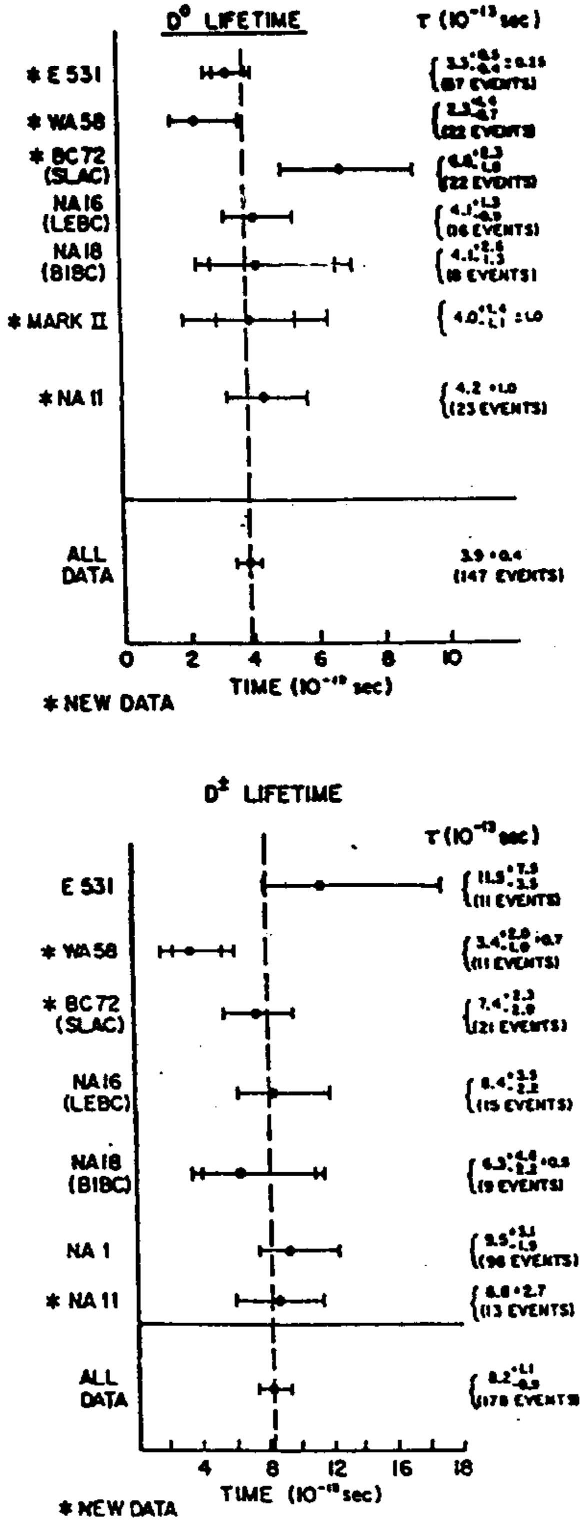

Fig. 13. Status of D^+ and D^0 meson lifetime measurements.

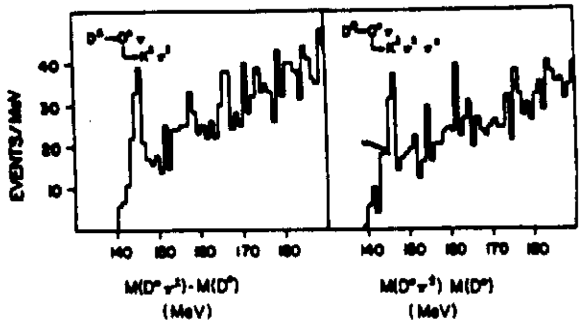

Fig. 14. D^* signal measured in the E-~~645~~ 516 photoproduction experiment.

E-623. It is a byproduct of a search for η_c decay into $\phi\phi$. Within a data sample containing 4 charged kaons, evidence has been found for the Cabbibo forbidden decay of D^+ into $\phi\pi$ as shown in Figure 15. There are about 240 entries in the peak,

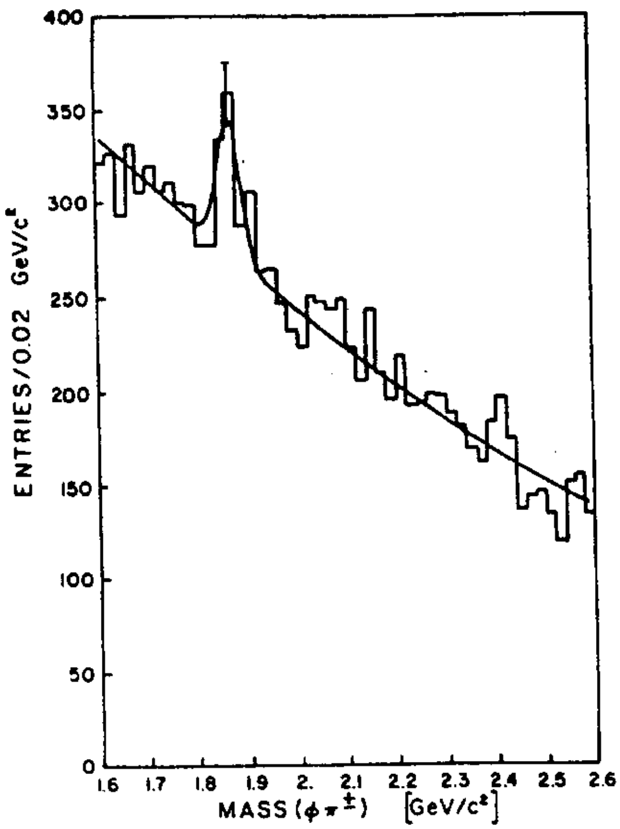

Fig. 15. The Cabibbo-forbidden decay $D \to \phi\pi$ observed in experiment E-623, designed to search for $\eta_c \to \phi\phi$.

which regrettably suffers from a very biased trigger because of the nature of the $\phi\phi$ search. Surprising is the absence of a corresponding F nearby since the branching ratio for F to $\phi\pi$ is a few percent, as measured by e^+e^- collider experiments. One might expect the production cross section ratio F^+/D^+ to be of order 10%. Thus a comparable F peak might have been seen. However, the experimentalists caution that because of the bias in the trigger one should not draw strong conclusions about the relative production of F to D from this measurement. Low statistics evidence for comparable strengths of F and D production does exist from the ACCMOR experiments NA11/32 at CERN. In any case, this $\phi\pi$ decay mode looks very promising for future studies of charm, in particular for comparison of the relative production dynamics of F and D in hadron collisions.

The upcoming program in charm physics at Fermilab contains several experiments. In this coming running period experiment E-691, a continuation of tagged-photon photoproduction, will utilize a transverse energy trigger which ought to enhance the charm signal. Silicon strip vertex detection has been added as well. Experiment E-653 will use protons incident on an emulsion-plus-silicon-strip target followed by a multiparticle spectrometer of high resolution. With use of the downstream spectrometer, vertices in the emulsion may be located with sufficient accuracy to allow scanning of the events to be done in a reasonable length of time. Both these experiments promise to yield between 100 and 1000 reconstructed charms per "easy" exclusive channel.

Also, the "little European bubble chamber" LEBC has moved to Fermilab and will take data this year (E-743) in conjunction with the Fermilab multiparticle spectrometer. This experiment should yield quite unbiased cross-section measurements of charm production in hydrogen. In addition two high resolution bubble chambers (E-632, E-745) will take data this run in the neutrino beam. A sizeable charm sample should be seen.

Further down the line is experiment E-690, an ambitious enterprise which will utilize a sophisticated on-line fast trigger processor. Events will be reconstructed on-line by the processor, and a search will be made for exclusive channels. These will then be selected; those with charm candidates (or other options) will be retained for later analysis. A smaller version of this experiment is now running at Brookhaven. After the processor is proven out there, the experiment will be moved to Fermilab, probably within a year or so.

Finally, a second-generation broad-band photon beam experiment (E-687) will soon be set up. The spectrometer used in this experiment promises to be as powerful as any at Fermilab. It will be a very strong facility for charm and bottom studies in the future. It can operate not only in photon beams but also a variety of hadron beams.

VI. BEYOND THE STANDARD MODEL

In general, the Tevatron fixed target program must be said to be programmatic. That is, it deals mainly within the standard model with phenomena which need to be better understood and parameters which need to be better measured. However, there do exist discovery opportunities which go beyond the standard model. One of these is the long-standing problem of same sign dilepton production by neutrinos. In several experiments it has been found that the process

$$\nu N \to \mu^-\mu^- X$$

occurs at a rate too high to be easily explained by conventional sources of background. A new measurement using the Fermilab 15 ft bubble chamber (E-53) was reported at this meeting of the very closely related process $\nu N \to \mu^- e^- X$, this process is not seen at the level of observation claimed for same-sign dimuon production. This may indicate either that the same-sign dimuon effect is spurious or that the effect is real, but violates μe universality. This latter hypothesis need not be considered too radical if indeed something crazy is the source of the phenomenon. Because the purported $\bar{\mu}\,\bar{\mu}$ signal appears to increase with energy, the upcoming neutrino running with 800 GeV primary protons should have much higher sensitivity to this process.

Another possibility of discovery physics has been stimulated by the observation of the ζ at DESY by the Crystal Ball collaboration. I am not fully convinced that the phenomenon has gone away despite the negative second round results, because to my knowledge the hypothesis of Tye and Rosenzweig has not been fully refuted. To me their model is the most reasonable explanation of the original results. In order to refute it requires precise knowledge of operating conditions of the machine in both the original run and in subsequent running. (Ideally, one would want to run some fraction of the time at one sigma or so off the resonant peak of the Υ on each side in order to be sure that the Tye mechanism is inoperable.) The relevance of this phenomenon to the Fermilab fixed target program has to do with experiment E-605, already mentioned in connection with high p_T dihadron production. This is the follow-up experiment to the one which discovered the Υ particle. In the next running period the emphasis will be on high intensity, with observation of dimuons with high mass resolution (20 MeV?). This resolution will be sufficient to cleanly resolve the various upsilon excited states. If there is any ζ-like entity, there is a good chance of seeing it. If Tye and Rosenzweig are right, one might see a first excited state somewhere around 9 GeV.

Yet another fixed target experimental program which contains discovery potential is the set of beam-dump experiments (E-635, 636, 646). The bread-and-butter part of that program is direct observation of the tau neutrino and study of its properties. However, beam dumps provide good opportunities to search for axions, neutral leptons, and the long lived neutral penetrating particles of supersymmetric theories. The monojet events from UA1 provide new stimulus for these kinds of searches, because a reasonable hypothesis for explaining the monojets is decay of the Z into a new neutral, long-lived penetrating particle plus the jet.

However, the beam dump program at Fermilab is in trouble. Although there are three approved experiments and a satisfactory dump design (Fig. 16), the facility is expensive. Because of funding shortfalls at Fermilab, it has been decided to defer beam dump construction in order not to disrupt too much of the remaining program. In order to minimize the delay the laboratory and DOE have submitted a line-item construction request for the FY'87 high energy physics budget to fund this facility.

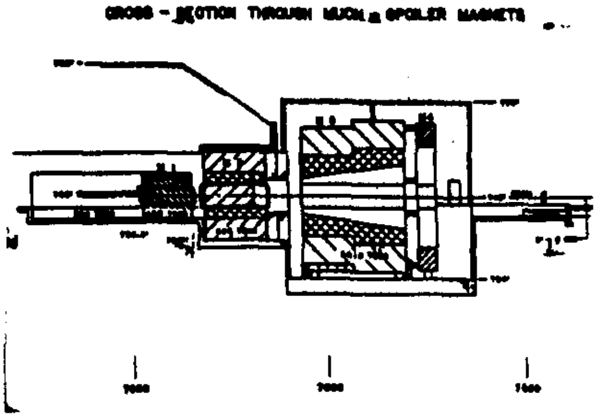

Fig. 16. Design for the Fermilab Prompt Neutral Lepton Facility.

VII. THE TEV II PROBLEM

The status of the beam dump is one example of a general problem (Fig. 17) which the TeV II program faces. As I see it, this problem has a three-fold source. The first source is the user perceptions of delays, insufficient lab support, insufficient agency support, competition with TeV I, as well as possibly greater security of the future of a group within a large colliding beam facility. There may also be a physics issue: the lack of being at the high energy frontier where the physics is likely to be more programmatic and have less headline-making potential. The source of the delays as seen by the Laboratory is that there is simply not enough money to do the job. And it does not help if the Laboratory, when viewing the user community, sees a flagging of interest and/or lack of stamina. The third source of the problem comes from the national scene, where funding agencies, HEPAP, and other nationally-based advisory groups may see too many competing demands for funds, given all the collider initiatives here and abroad, as well as underground experiments, and R&D for the SSC. TeV II looks like just one more program competing with

The TeV II Problem

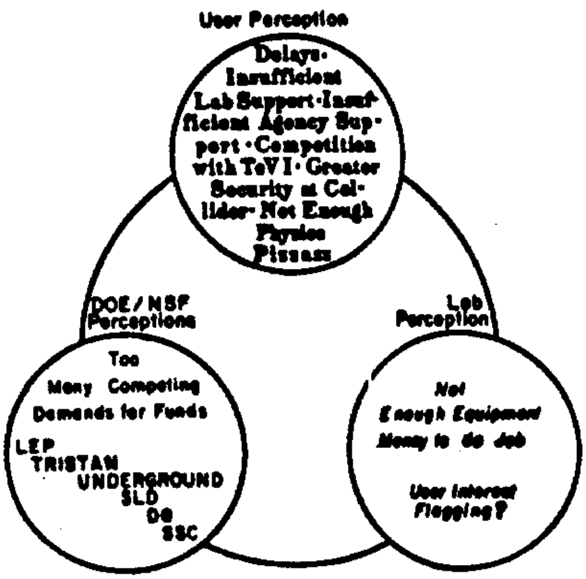

Fig. 17. Three-way vicious circle underlying existing problems with the fixed target program.

all the others, despite its diversity and breadth. Since it is a broadly-based program with many components it also is a prime candidate for cuts. Anyone looking at the program will have his or her favorite experiment and his or her turkey. The problem is that if one puts a dozen people in a room, absolutely no agreement is found on which experiment is the turkey. Thus, everyone will agree that something can be cut out of the program without anybody noticing but no one can agree on how to do it without severe damage, with everyone noticing.

VIII. LONGER RANGE OPPORTUNITIES

Such pessimistic words about the fixed target program should not be meant to indicate that, in fact, the physics is drying out. As we have seen, there is very much to be done. The physics is extremely good and the opportunities are of high quality. In the realm of big initiatives one of my favorites is a next-generation round of heavy-quark physics. This may require a new spectrometer facility, one which can go an order of magnitude beyond what is hoped for in the upcoming runs. I would like to see 10^4 to 10^5 detected charms per easy channel as the goal. There is a question of how to proceed with such a large initiative - or whether one should proceed. One option is to rely on existing initiatives in the program or new initiatives of comparable scale. The arguments in favor of this are that it would exploit optimally the expertise of existing teams and provide continuity with the programs now going on. Secondly, the physics with several groups would come out in parallel, with competition providing additional stimulus. And one might not need escalation in group size or apparatus to do the job. Also, one might cite examples of very big comprehensive spectrometers which haven't done as well as more modest apparatus with greater specificity.

On the other hand, the physics may simply require, just as it has in colliding beams, concentrating most of the effort into a very big centralized facility which might approach collider detectors in size and scope. It may be arguable that existing groups doing charm and bottom physics are too small, and that the spectrometers which are being built or exist now are simply not powerful enough to do this kind of physics. Certainly a necessary condition for physics at this level is that a variety of incident beams should be available, not only protons but also neutrons, mesons, hyperons and photons as well. One will need to make comparisons, as well as produce a variety of different kinds of hadrons containing heavy quarks. Another argument for a very big facility is its visibility; it is easier for the national community to notice and thus support. Finally, another reason for a large charm-bottom spectrometer may have to do with the SSC. If \$200 to \$500 million will be spent on detectors for the SSC, there should be a considerable amount of R&D devoted to that enterprise. This R&D must go beyond paper designs and construction of small modules which are put into test beams. Systems which are large enough to capture an entire hadron jet of several hundred GeV (a bread and butter phenomenon for the SSC) should be tested. Secondary beams at Fermilab are certainly a very good source of such jets. Certainly Fermilab should provide facilities for this kind of R&D. But, just like all R&D efforts, if there is physics that can be attached to the instrumental development, the whole effort will be better focused, gain more momentum and in general have greater productivity. Therefore it seems reasonable that Fermilab, while welcoming detector R&D done in its secondary beams, will welcome even more those initiatives which have a strong physics motivation as well. Therefore it may make sense to integrate SSC detector R&D into a large heavy-quark spectrometer program.

I do not myself have a fixed opinion on whether the "small" or big option is the better one. I do believe that it is none too early to start thinking about this, and that by the summer Fermilab and its program committee ought to plan and develop policy on how to proceed further in exploiting the opportunities in heavy quark physics at Fermilab.

At the opposite extreme, there are opportunities for small initiatives within the fixed target program. Examples now discussed or presently pursued include a program on crystal channeling which may even have applications to accelerator physics (including SSC) in providing small septum magnets, measurement of the magnetic moment of Ω^-, quark searches, searches for rare decays such as $\Xi^0 \to p\pi^-$, searches for anomalons, and soft muon physics. These have obvious sociological importance in this age of giant collaborations. But they must stand on their own in terms of physics quality. I think most do.

There exist more exotic possibilities in fixed target physics, such as colliding stored antiprotons on gas targets to resonantly produce ψ and χ states, such as done at the CERN ISR. Storing muons and pions in order to make low energy neutrino beams has also been discussed from time to time. The desirability of doing this depends somewhat on the future of neutrino mass measurements. Certainly if neutrino masses and mixings are convincingly found to be non-vanishing there may well be a renaissance of interest in this kind of physics at Fermilab.

In any case, the bottom line on the future of fixed target physics is one of commitment. Much very good physics is there to be done. The necessary condition is that there be enough people who are willing to do the hard work to get it out.